

Advanced Flue Gas Desulfurization Demonstration Project

Project completed

Participant

Pure Air on the Lake, L.P. (a project company of Pure Air, which is a general partnership between Air Products and Chemicals, Inc., and Mitsubishi Heavy Industries America, Inc.)

Additional Team Members

Northern Indiana Public Service Company—cofunder and host

Mitsubishi Heavy Industries, Ltd.—process designer
Stearns-Roger Division of United Engineers and Constructors—facility designer

Air Products and Chemicals, Inc.—constructor and operator

Location

Chesterton, Porter County, IN (Northern Indiana Public Service Company's Bailly Generating Station, Unit Nos. 7 and 8)

Technology

Pure Air's advanced flue gas desulfurization (AFGD) process and PowerChip® agglomeration process

Plant Capacity/Production

528 MWe

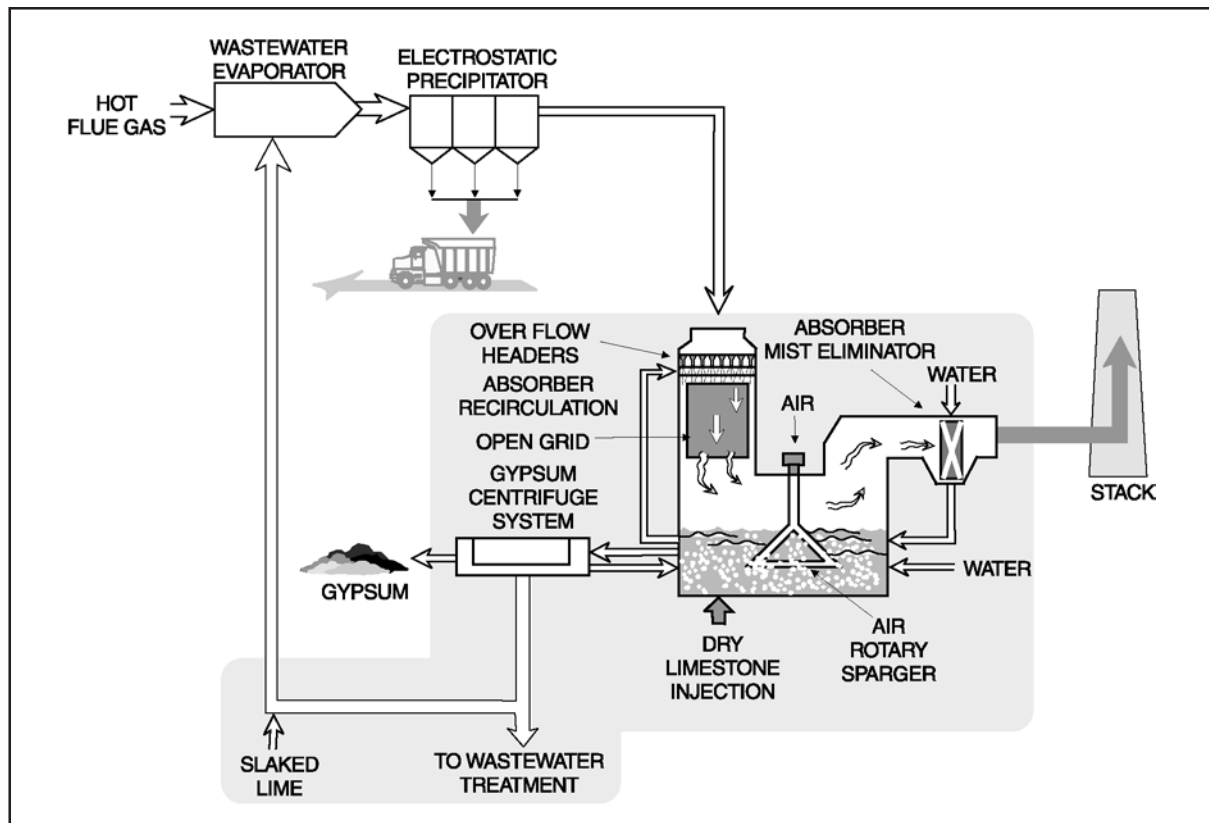
Coal

Bituminous, 2.25–4.5% sulfur

Project Funding

Total	\$151,707,898	100%
DOE	63,913,200	42
Participant	87,794,698	58

PowerChip is a registered trademark of Pure Air on the Lake, L.P.



Project Objective

To reduce SO₂ emissions by 95% or more at approximately one-half the cost of conventional scrubbing technology, significantly reduce space requirements, and create no new waste streams.

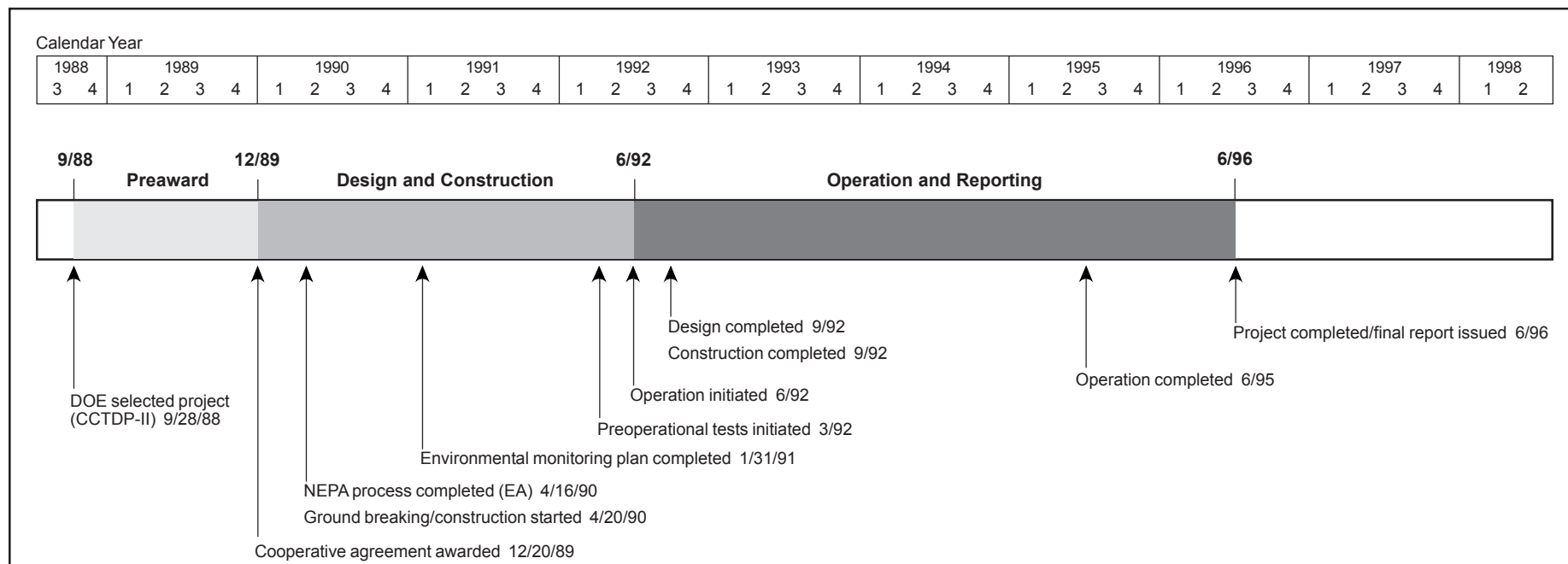
Technology/Project Description

Pure Air built a single SO₂ absorber for a 528-MWe power plant. Although the largest capacity absorber module of its time in the United States, space requirements were modest because no spare or backup absorber modules were required. The absorber performed three functions in a single vessel: prequenching, absorbing, and oxidation of sludge to gypsum. Additionally, the absorber was of a co-current design, in which the flue gas and scrubbing slurry move in the same direction and at a relatively high velocity compared to that in conventional

counter-current scrubbers. These features all combined to yield a state-of-the-art SO₂ absorber that was more compact and less expensive than contemporary conventional scrubbers.

Other technical features included the injection of pulverized limestone directly into the absorber, a device called an air rotary sparger located within the base of the absorber, and a novel wastewater evaporation system. The air rotary sparger combined the functions of agitation and air distribution into one piece of equipment to facilitate the oxidation of calcium sulfite to gypsum.

Pure Air also demonstrated a unique gypsum agglomeration process, PowerChip®, to significantly enhance handling characteristics of AFGD-derived gypsum.



Results Summary

Environmental

- The AFGD design enabled a single 600-MWe absorber module without spares to remove 95% or more SO₂ at availabilities of 99.5% when operating with high-sulfur coals.
- Wallboard-grade gypsum was produced in lieu of solid waste, and all gypsum produced was sold commercially.
- The wastewater evaporation system (WES) mitigated expected increases in wastewater generation associated with gypsum production and showed the potential for achieving zero wastewater discharge (only a partial-capacity WES was installed).
- Air toxics testing established that all acid gases were effectively captured and neutralized by the AFGD. Trace elements largely became constituents of the solids streams (bottom ash, fly ash, and gypsum product). Some boron, selenium, and mercury passed to the stack gas in a vapor state.

Operational

- AFGD use of co-current, high-velocity flow; integration of functions; and a unique air rotary sparger proved to be highly efficient, reliable (to the exclusion of requiring a spare module), and compact. The compactness, combined with no need for a spare module, significantly reduced space requirements.
- The own-and-operate contractual arrangement—Pure Air took on the turnkey, financing, operating, and maintenance risks through performance guarantees—was successful.
- PowerChip® increased the market potential for AFGD-derived gypsum by cost-effectively converting it to a product with the handling characteristics of natural rock gypsum.

Economic

- Capital costs and space requirements for AFGD were about half those of conventional systems.

Project Summary

The project proved that single absorber modules of advanced design could process large volumes of flue gas and provide the required availability and reliability without the usual spare absorber modules. The major performance objectives were met.

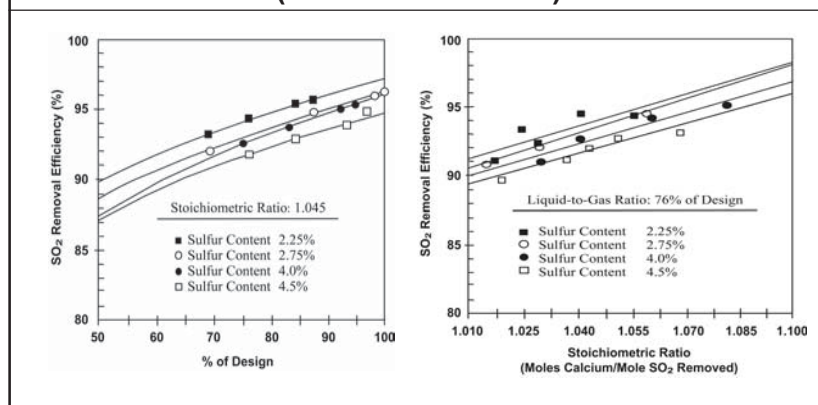
Over the three-year demonstration, the AFGD unit accumulated 26,280 hours of operation with an availability of 99.5%. Approximately 237,000 tons of SO₂ were removed, with capture efficiencies of 95% or more, and over 210,000 tons of salable gypsum were produced. The AFGD continues in commercial service, which includes sale of all by-product gypsum to U.S. Gypsum's East Chicago, Indiana wall-board production plant.

Environmental Performance

Testing over the three-year period clearly established that AFGD operating within its design parameters (without additives) could consistently achieve 95% SO₂ reduction or more with 2.25–4.5% sulfur coals. The design range for the calcium-to-sulfur stoichiometric ratio was 1.01–1.07, with the upper value set by gypsum purity requirements (*i.e.*, amount of unreacted reagent allowed in the gypsum). Another key control parameter was the ratio L/G, which is the amount of reagent slurry injected into the absorber grid (L) to the volume of flue gas (G). The design L/G range was 50–128 gal/1,000 ft³. The lower end of the L/G ratio was determined by solids settling rates in the slurry and the requirement for full wetting of the grid packing. The high end of the L/G ratio was determined by where performance leveled out.

Four coals with differing sulfur contents were selected for parametric testing to examine SO₂ removal efficiency as a function of load, sulfur content, stoichiometric ratio, and L/G. Loads tested were 33%, 67%, and 100%. High removal efficiencies, well above 95%, were possible at loads of 33% and 67% with low to moderate stoichiometric ratio and L/G settings, even for 4.5% sulfur coal. Exhibit 3-13 summarizes the results of parametric testing at full load.

Exhibit 3-13
Pure Air SO₂ Removal Performance
(100% Boiler Load)



In the AFGD process, chlorides that would have been released to the air are captured, but potentially become a wastewater problem. This was mitigated by the addition of the WES, which takes a portion of the wastewater stream with high chloride and sulfate levels and injects it into the ductwork upstream of the ESP. The hot flue gas evaporates the water and the dissolved solids are captured in the ESP. Problems were experienced early on with the WES nozzles failing to provide adequate atomization and plugging. These problems were resolved by replacing the original single-fluid nozzles with dual-fluid systems employing air as the second fluid.

Commercial-grade gypsum quality (95.6–99.7%) was maintained throughout testing, even at the lower sulfur concentrations where the ratio of fly ash to gypsum increases due to lower sulfate availability. The primary importance of producing a commercial-grade gypsum is avoidance of the environmental and economic consequences of disposal. Marketability of the gypsum is dependent upon whether users are in range of economic transport and whether they can handle the gypsum by-product. For these reasons, PowerChip® technology was demonstrated as part of the project. This technology uses a compression mill to convert the highly cohesive AFGD gypsum cake into a flaked product with handling charac-

teristics equivalent to natural rock gypsum. The process avoids use of binders, pre-drying, or pre-calcining normally associated with briquetting, and is 30–55% cheaper at \$2.50–\$4.10/ton.

Air toxics testing established that all acid gases are effectively captured and neutralized by the AFGD. Trace elements largely become constituents of the solids streams (bottom ash, fly ash, gypsum product). Some boron, selenium, and mercury pass to the stack gas in a vapor state.

Operational Performance

Availability over the 3-year operating period averaged 99.5% while maintaining an average SO₂ removal efficiency of 94%. This was attributable to the simple, effective design and an effective operating/maintenance philosophy. Modifications contributed to the high availability. An example was the implementation of new alloy technology, C-276 alloy over carbon steel clad material, to replace alloy wallpaper construction within the absorber tower wet/dry interface. The use of co-current rather than conventional counter-current flow resulted in lower pressure drops across the absorber and afforded the flexibility to increase gas flow without an abrupt drop in removal efficiency. The AFGD SO₂ capture efficiency with limestone was comparable to that in wet scrubbers using lime, which is far more expensive. The 24-hour power consumption was 5,275 kW, or 61% of expected consumption, and water consumption was 1,560 gal/min, or 52% of expected consumption.

Economic Performance

Exhibit 3-14 summarizes capital and levelized 1995 current dollar cost estimates for nine cases with varying plant capacity and coal sulfur content. A capacity factor of 65% and a sulfur removal efficiency of 90% were assumed. The calculation of levelized cost followed guidelines established in EPRI's *Technical Assessment Guide*™.

The incremental benefits of the own-and-operate arrangement, by-product utilization, and emission allowances were also evaluated. Exhibit 3-15 depicts the relative

Exhibit 3-14 Estimated Costs for an AFGD System (1995 Current Dollars)

Cases:	1	2	3	4	5	6	7	8	9
Plant size (MWe)	100	100	100	300	300	300	500	500	500
Coal sulfur content (%)	1.5	3.0	4.5	1.5	3.0	4.5	1.5	3.0	4.5
Capital cost (\$/kW)	193	210	227	111	121	131	86	94	101
Levelized cost (\$/ton SO ₂)									
15-year life	1,518	840	603	720	401	294	536	302	223
20-year life	1,527	846	607	716	399	294	531	300	223
Levelized cost (mills/kWh)									
15-year life	16.39	18.15	19.55	7.78	8.65	9.54	5.79	6.52	7.24
20-year life	16.49	18.28	19.68	7.73	8.62	9.52	5.74	6.48	7.21

costs of a hypothetical 500-MWe generating unit in the Midwest burning 4.3% sulfur coal with a base case conventional FGD system and four incremental cases. The horizontal lines in Exhibit 3-15 show the range of costs for a fuel-switching option. The lower line is the cost of fuel delivered to the hypothetical midwest unit, and the upper line allows for some plant modifications to accommodate the compliance fuel.

Commercial Applications

The AFGD technology is positioned well to compete in the pollution control arena of the 21st century. The AFGD technology has markedly reduced cost and demonstrated the ability to compete with fuel switching under certain circumstances even with a first-generation system. Advances in technology, *e.g.*, in materials and components, should lower costs for AFGD. The own-and-operate business approach has done much to mitigate risk on the part of prospective users. High SO₂ capture efficiency offers the AFGD user the possibility of generating allowances or applying credits to other units within the utility. WES and PowerChip[®] mitigate or eliminate otherwise serious environmental concerns. AFGD effectively deals with hazardous air pollutants.

The project received *Power* magazine's 1993 Powerplant Award and the National Society of Professional Engineers' 1992 Outstanding Engineering Achievement Award.

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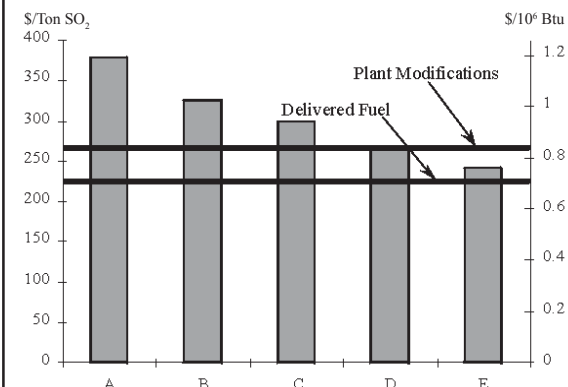
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References

Summary of Air Toxics Emissions Testing at Sixteen Utility Power Plants. Prepared by Burns and Roe Services Corporation for U.S. Department of Energy, Pittsburgh Energy Technology Center. July 1996.

Exhibit 3-15 Flue Gas Desulfurization Economics



500-MWe plant, 30-yr levelized costs, allowance value of \$300/ton

Incremental cases:

A—Conventional FGD (EPRI model)

B—AFGD, own-and-operate arrangement

C—Adds gypsum sales

D—Adds emission allowance credits at \$300/ton, for 90% SO₂ removal

E—Increases SO₂ removal to 95%

Advanced Flue Gas Desulfurization (AFGD) Demonstration Project. Final Technical Report, Vol. II: Project Performance and Economics. Pure Air on the Lake, L.P. April 1996. (Available from NTIS as DE96050313.)

Advanced Flue Gas Desulfurization Project: Public Design Report. Pure Air on the Lake, L.P. March 1990.

Advanced Flue Gas Desulfurization Demonstration Project—Project Performance Summary. U.S. Department of Energy. June 1999.